urban Canadians. The physician must adapt to these differences and avoid imposing his own perspective. The same is true on orbit, with crews generally of international composition.

Risk management

Living in a remote area is a health risk in itself: for example, the chances of surviving a major head trauma are several orders of magnitude lower when the nearest neurosurgeon and ICU are several hours away by flight. Remoteness also drives the way we organize patient follow-up for more benign ailments: northern physicians tend to err on the conservative side, in general, to further minimize risks of complications.

The local population understands and accepts these risks; the challenge for northern health care providers, and the responsibility of the healthcare system, is to ensure these discrepancies are minimized, within reason. To quote an Inuit participant to the Romanow Commission: "I believe that the success of our Health Care System as a whole will be judged not by the quality or service available in the best urban facilities, but by the equality of service Canada can provide to its remote and northern communities."

Similar concerns apply to on-orbit medical care. For example, in deciding the content of the on-board medical kit, one must decide what pathologies the crew could likely treat successfully. Deciding whether a particular illness or injury is survivable or not on-orbit is a matter of ongoing speculation and debate. This uncertainty is essentially what drives the requirement for crewmembers to undergo such stringent medical screening, in the hope of minimizing risk.

Again, as we envision deep-space missions wherein medical evacuation is not an option, the sobering consideration of what one should realistically prepare to treat only gets more relevant.

David Saint-Jacques (MD, PhD) is an astronaut candidate with the Canadian Space Agency. He and is currently in basic training at NASA's Johnson Space Center in Houston, Texas. He was selected in 2009 while he was working as a family physician in the Inuit community of Puvirnituq, in Nunavik, Northern Quebec. He received a B.Eng in engineering physics from École Polytechnique in Montreal, and worked as a biomedical engineer in Paris, France. He subsequently obtained a PhD in astrophysics at Cambridge University, UK and worked as an astrophysicist in Tokyo, Hawaii and Montreal. He then returned to pursue an M.D. from Université Laval, and completed a residency in family medicine at McGill University.

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CROSSROADS

Physicians as Astronauts

Robert Thirsk*

In 2009 I had the good fortune to fly on a long duration space mission. With two crewmates, I launched aboard a Russian Soyuz rocket from the Baikonur Cosmodrome in Kazakhstan. When our spacecraft reached orbit nine minutes later, we were traveling at a speed of 28,000 kilometers per hour through an environment devoid of air, water and anything familiar. Two days later we rendezvoused with the International Space Station (ISS) at an altitude of 350 km. As our Soyuz vehicle docked with the Station, we began an incredible space odyssey as members of the ISS Expedition 20/21 crew.

This Expedition marked the first time that the ISS hosted a permanent crew of six. My international crewmates (from Russia, the United States, Japan and Belgium) and I performed an unprecedented amount of multidisciplinary research (Figure 1). We also performed complex robotic operations, spacewalks, and maintenance and repair work of Station systems and payloads (Figure 2).

Six months later my Soyuz crewmates and I undocked from the Station and landed back in Kazakhstan. During our stay in space, we completed 3,000 orbits of the Earth and traveled 125,000,000 km. It was truly an odyssey.

This ISS expedition as well as my earlier Space Shuttle mission have enriched me in ways I can never fully explain. I often reflect on the career path that took me from medicine to the cosmos. To some of my medical colleagues, this path seems incongruous. They ask, "What does the practice of medicine have in common with space exploration?".

In the following paragraphs, I describe the astronaut profession and its commonalities with medicine. Astronaut training is certainly a transformative experience and the spaceflight environment

Figure 1: European astronaut Frank De Winne performs echocardiography on Robert Thirsk, MDCM. This experiment investigated cardiovascular adaptation to weightlessness.

is alien to anything in the clinical world. However, a career transition to space exploration after investing so much time and effort in a medical career is not unusual. A well-trained astronaut exhibits many of the same knowledge, skills and professional attributes of an exemplary physician. Indeed, a medical background forms an excellent foundation for a career in astronautics.

SELECTION

An astronaut career begins with selection. The process to become an astronaut is even more protracted, competitive and rigorous than it is for medical school. The Canadian Space Agency's most recent recruitment campaign in 2008/09 lasted 12 months and saw 5,300 people apply for only two available positions.

Astronaut candidates represent a wide spectrum of professionals such as test pilots, engineers, scientists, educators and physicians. Candidates who have considerable experience working

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Figure 2: Robert Thirsk, MDCM, performs maintenance on the Station's Water Recovery System. This recycling system processes waste water and crew urine into potable water.

in a team setting and who habitually work outside their comfort zones are highly regarded (Figure 3).

Like prospective medical students, astronaut candidates complete questionnaires and submit university transcripts, letters of reference and a personal essay ("why I want to be an astronaut") as part of the application process. During the latter stages of the selection process, a series of interviews are conducted with the selection committee. A very thorough medical evaluation is performed since many medical conditions that are considered to be minor on Earth can become problematic in a spaceflight environment.

The work of an astronaut regularly takes us to the limits of our physical, mental and emotional abilities. Accordingly, the selection process includes physical fitness, cognitive and psychiatric evaluations. Hours of psychometric tests and psychological interviews ensure that the chosen candidates have the motivation, personalities and support mechanisms to do well in the demanding training and flight environments.

Aptitude tests assess a candidate's team skills, creativity and tolerance to stress. During the most recent recruitment campaign, the candidates' potential to learn specialized skills such as robotics, EVA (Extra Vehicular Activity) and foreign languages was also considered.

Finally, interpersonal and communication skills are evaluated. In addition to operational duties, astronauts function as spokespersons for the Canadian Space Agency. We advocate for a national economy based upon innovation and advanced training. In the same way that we were inspired by explorers and scientists when we were young, it is our responsibility to engage the public and to instill a passion for discovery in Canada's next generation of leaders.

KNOWLEDGE

Following selection (a gratifying day for a fortunate few!), astronauts begin the first phase of our education called Basic Training. This phase typically lasts a couple of years. Basic Training provides each new astronaut (no matter what prior professional background) with a common knowledge base and builds the foundation for more advanced training to follow in the ensuing years. Each new recruit acquires broad background knowledge about the scientific, technical and operational aspects of human spaceflight.

The structure of the basic training program for an astronaut shares a lot in common with a medical school curriculum. Our training resources include manuals, lectures, computer-based instruction and field trips.

The first couple of years of medical school were challenging for me due to the massive amount of knowledge that needed to be learned quickly. The same is true in astronautics. Astronaut training is like drinking from a fire hose. The Russian Soyuz and the American Space Shuttle are complex space vehicles. Even more challenging to understand and operate is the International Space Station (Figure 4). This marvel of engineering has a mass of 420 tons, dimensions that are two times greater than that of a CFL football field, and living space equivalent to a four-bedroom house. 120 telephone-booth-size racks house spacecraft systems and research experiments. The Station's onboard computers process four million lines of code.

A systems approach is used to instruct astronauts about space operations. We consider the composition of our spacecraft to include thermal control, electrical power, life support and many other systems. Just as no system in the human body operates independently, each spacecraft system interacts with several others.

Physicians and astronauts would be equally handicapped if we could not resort to our unique mnemonics. Acronyms and jargon pepper our conversations with colleagues. I smile to myself whenever I encounter a new space acronym that shares a meaning from my medical past (e.g. ER, D&C).

SKILLS

Having acquired the fundamentals of spaceflight operations, astronauts next begin a training phase known as Advanced Training. This phase of training is analogous to clinical clerkship and residency since we learn highly specialized skills that are unique to our profession. It is fast-paced and fulfilling.

We learn skills that allow us to launch to and return from orbit, to rendezvous and dock with other spacecraft, to perform spacewalks (also known as EVAs) and to operate robotic systems such as the Canadarm2. After acquiring proficiency in a skill, we become mentors to the next trainees. 'See one, do one, teach one' is a mantra that also applies to spaceflight.

Practice makes perfect. We train thousands of hours for nominal as well as off-nominal situations. Crew coordination, situational awareness and speed of reaction are critical factors to save our lives, the spacecraft and the mission under contingency situations.

It is during Advanced Training that simulators play a major role. In fact, simulators are the basis for much of our skills acquisition. They are used to prepare astronauts for a variety of flight situations.

For instance, the robotics simulator at the Canadian Space Agency in Montréal uses virtual reality to model Canadarm2, other robotic systems and the Space Station environment. Astronauts from all ISS partner nations use this facility to develop skills such as Station assembly and the capture and berthing of cargo vehicles.

The Neutral Buoyancy Laboratory (NBL) in Houston, Texas is another type of simulator. It is basically a huge pool (much larger than an Olympic swimming pool). We exploit water buoyancy to simulate the weightless condition experienced by astronauts during space walks. Small flotation devices or weights are strapped to the space suits

Figure 3: During her STS-42 Shuttle mission Roberta Bondar, MD, begins an experiment to investigate visual and vestibular responses to head and body movements.

Figure 4: The International Space Station viewed from the Space Shuttle at orbital sunset.

of astronauts so that we are neutrally buoyant and so that our movements in water are similar to what they would be in space (except for the effect of water drag). The NBL is an essential simulator to familiarize us with space walk plans and procedures (Figure 5).

The Gagarin Cosmonaut Training Centre near Moscow has an impressive centrifuge with a rotating arm that is 18-meters long (the largest in the world). The distal end of the arm contains a functional mock-up of the Soyuz cockpit. This is where cosmonauts sit. As the arm rotates, the centrifuge creates the g-forces similar to what we experience in our capsule during atmospheric re-entry. The level of g-force induced by the centrifuge is determined solely by the re-entry profile that we manually fly from the controls in the cockpit. In other words, we pay for any piloting mistakes we may make with a high g-load! Talk about incentive for the trainee to get it right!

There are many other simulators used for astronaut training and they come in a variety of appearances and functions. No single simulator can recreate all conditions of spaceflight. However, each is able to simulate one or more features in high fidelity. By integrating our training experiences across all of these simulators, we are well prepared for what we will encounter on orbit.

Another valuable training resource is NASA's fleet of T-38 high performance jets (Figure 6). These aircraft are not simulators; they provide real-life dynamic training. Jet flight, like spaceflight, involves interaction with complex, data-rich systems in a fast-paced, unforgiving environment. Flight time in high performance jets sharpens decision-making skills and crew coordination.

ATTITUDES

An ISS crew of six possesses all the necessary skills to deal with any onboard situation. Each crewmember fulfills a certain role and is proficient in several specialized skills (in addition to generic crew skills). For instance, during Expedition 20/21, I functioned as a flight engineer, and my specialized responsibilities included medical care for the crew, payload science and robotics. While the crew commander had overall responsibility, each crew member played a leadership role for specific aspects of the expedition.

The harmonious teamwork exhibited by my Shuttle and Station crews is something I fondly remember. In addition to his or her own busy schedule of duties, each of my crewmates became involved in the successful completion of others' tasks. We anticipated each other's unspoken needs in the same way that an operating room nurse anticipates the next instrument required by a surgeon. After completing our own tasks, we then looked for opportunities to help our crewmates with theirs. For instance, I would arrive at a worksite aboard the Station and find that someone had already gathered the tools that I would require for my upcoming task. What a team!

Everyone helps out with everything. Accordingly, when one crew member successfully completes a complex operation, we all share in the satisfaction. This kind of crew interaction enhances our productivity and makes our activities seem tightly choreographed.

Like all health care practitioners, astronauts are vigilant and precise about everything we do. During spaceflight there is often only one chance to perform a task correctly. The speed of the spacecraft, the constraints of orbital dynamics or the tight mission timeline often mean that there are no second chances.

Launch, rendezvous and re-entry are phases of flight to be particularly vigilant. Thoughts about the next possible failure pre-occupy our minds while executing engine burns and on-orbit maneuvers. Monitoring our instruments for system malfunctions is not enough; we also need to anticipate the next failure, its impact and our reaction.

Most astronauts are not familiar with the clinical precept "Primum Non Nocere" but we do adhere to its intent. When a crewmate begins a critical task, we often admonish her or him with the

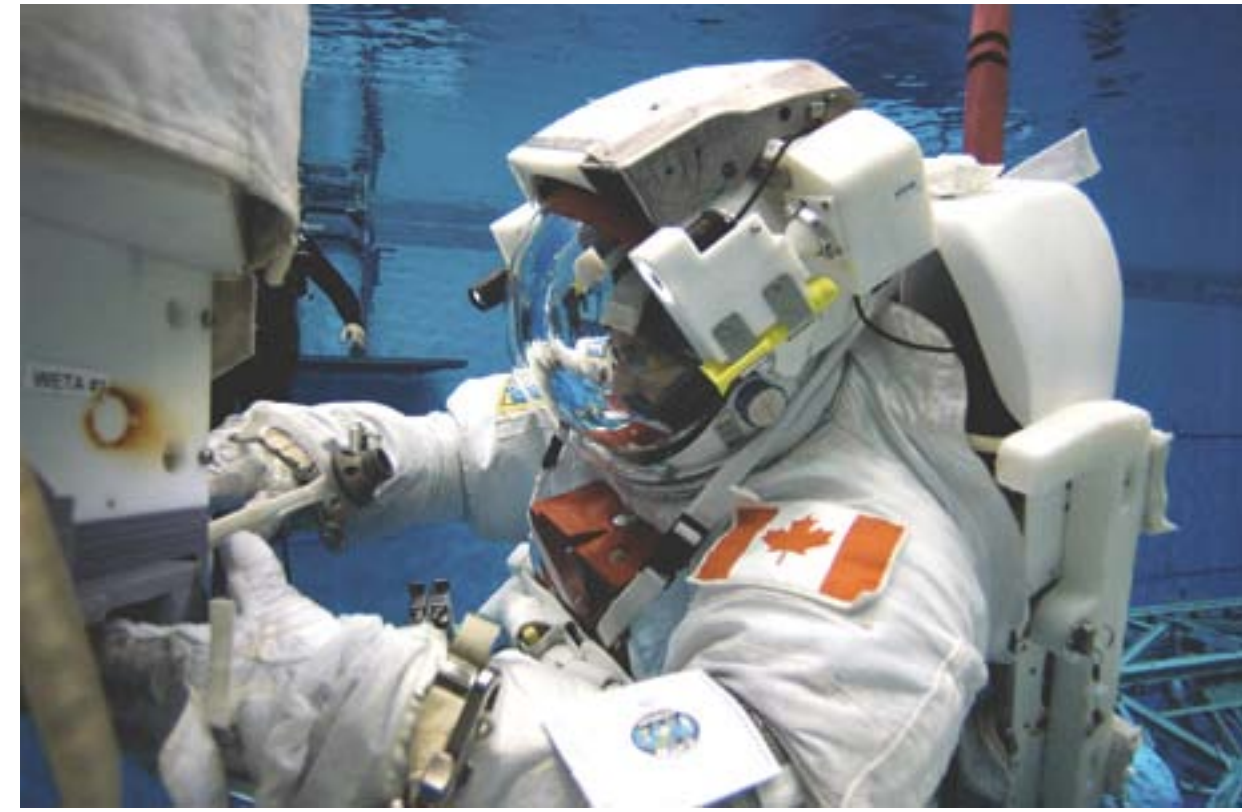

Figure 5: Dave Williams, MDCM, rehearses EVA procedures in the Neutral Buoyancy Facility prior to his STS-118 Shuttle mission.

words "don't become famous!" If the name of an astronaut becomes well known, it is often because she or he made a mistake while on-orbit. In the following years, our instructors on the ground will lightheartedly mention the goof-up and our name to forewarn the next classes of astronauts about potential operational pitfalls. I would be happy to complete my career as an unknown!

Doctors do not work in isolation from the rest of the hospital staff. Clerks, orderlies, technicians, social workers, physiotherapists and the omniscient head nurse are key members of the patient care team. Astronauts also do not work in isolation. Thousands of kilometers away at mission control centres around the world, hundreds of engineers, scientists, technicians, flight surgeons and managers (known collectively as 'flight controllers') continuously monitor our spacecraft's telemetry, video and audio signals. The flight controllers have great insight into the status of our vehicle's systems and payloads, and are ready to spring into action if an in-flight anomaly should occur.

Anomalies and hardware failures can be expected during the course of every mission. For example, during Expedition 20/21 our oxygen generation and carbon dioxide removal systems failed. At these times I considered the flight controllers as specialists and regarded my role in space as their eyes, ears, and hands. Oslerian observation and communication skills that I had developed as a physician became useful. Having completed the 'history' and examination of the failed system, I then communicated my observations concisely to the flight controllers and anticipated what other information they would need to diagnose the problem. Working together, we successfully repaired these critical systems. Flight controllers are integral members of our team and I have great confidence in their capabilities.

Physicians may be the most senior practitioners on a hospital ward and astronauts may be the most visible participants of a mission, but we are only small subsets of large talented teams devoted to success.

A space mission continues even after we return to Earth. Astronauts spend several weeks after landing in medical testing and physical rehabilitation. We don't consider the mission complete until the debriefings are finished.

No mission has ever been flown perfectly. Hardware inevitably breaks down and contingency situations arise. Every astronaut will admit in hindsight that she or he could have executed a particular task more effectively. During debriefing sessions (our version of Grand Rounds), we recount our experiences for the benefit of instructors, flight controllers and program managers. This kind of feedback facilitates planning for future missions and enhances the training for the crews who will fly next. We learn and improve from our insights and errors.

CONCLUSION

Back on Earth, I often reflect on my medical school years and residency. Both were positive experiences. As a student I couldn't foresee the opportunities that my medical training would someday offer to me both on and off this planet.

It behooves space agencies, in summary, to recruit physicians for our unique training experiences and for the operational capabilities that we hone on hospital wards. Of Canada's ten astronauts, four are physicians. Three of these four physicians are graduates of McGill University's medical school (Figure 7). Not a bad batting average!

The knowledge, skills and attitudes of a clinician are valuable but not sufficient, of course, to be an astronaut. A burning passion for space exploration is also required. We take our inspiration from John F. Kennedy who, when the United States was initiating its Apollo moon program, declared "We choose to go to the moon, not because it is easy, but because it is hard, because that goal will serve to measure the best of our energies and skills."

For some people, the benefits of space exploration do not out-weigh the arduous work and risk. For physician-astronauts, they clearly do.

Figure 6: David Saint-Jacques, MD, returns from a training flight in a T-38 jet. These jets develop operator skills and crew coordination in a dynamic environment.

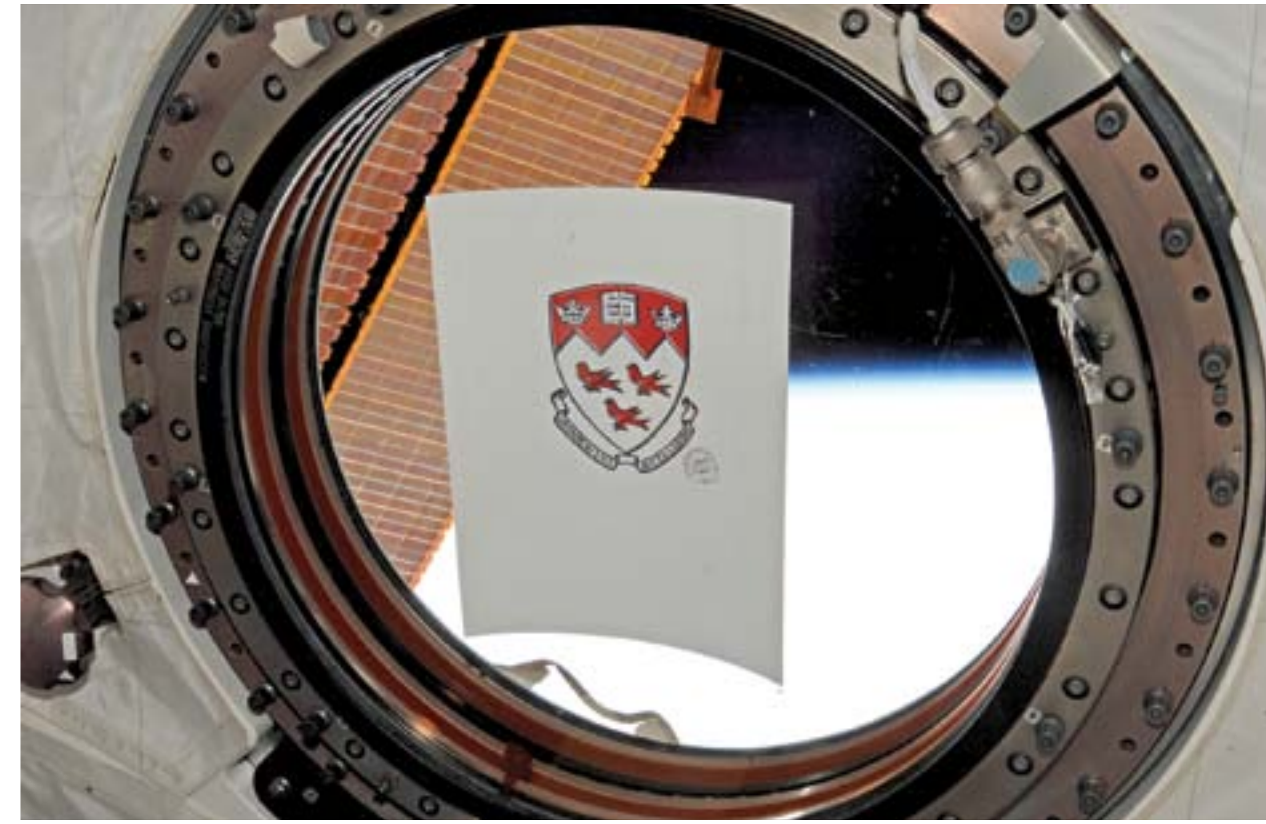

Figure 7: A McGill University crest was flown aboard ISS Expedition 20/21 to recognize the close ties between the McGill Medical School and Canada's astronaut corps.

Robert Thirsk received a Bachelor of Science degree in Mechanical Engineering from the University of Calgary, a Master of Science in Mechanical Engineering and a Master of Business Administration from the Massachusetts Institute of Technology, and a Doctorate of Medicine from McGill University. Robert has flown twice in space: a 17-day mission in 1996 aboard the Space Shuttle Columbia and a 188-day expedition in 2009 aboard the International Space Station.